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Featuring

The Design of Supporting Structures for Transmission Lines

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Volume XVII FEBRUARY, 1930 Number 2

THE DESIGN OF SUPPORTING STRUCTURES FOR TRANSMISSION LINES

(Presented at a Meeting of the Designers Section of the Boston Society of Civil Engineers, February 13, 1929)

ECONOMIC CONSIDERATIONS INVOLVED IN THE DESIGN OF TRANSMISSION LINE STRUCTURES

By C. A. Booker *

The transmission line is constructed for the purpose of conveying electrical energy from one point to another, and there are certain requirements laid down by the electrical engineer which have an important bearing on the ultimate design of the supporting structures. These requirements include consideration of operating voltage, the size of conductor, electrical characteristics of insulators, and the clearance from live wires to the nearest grounded members. These factors and numerous other considerations have a bearing on the economical determination of the general type of design and other characteristics affecting the loadings and configuration of the tower.

Poles for Power Line Supports

When it first became desirable to transmit electrical energy by means of overhead wires, man turned to his old structural standby, the tree, for the supporting structure, and this, in the familiar form of poles, has faithfully performed every duty thrust upon it, lining the highways and by-

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* Engineer, New England Power Construction Company, Boston, Mass.

ways by the million. The country's enormous resources in pole timber has, without doubt, been one of the chief contributing factors in the marvelous expansion of the use of electricity.

The wood pole offers in many ways an ideal structure for supporting wires. It is procurable in a wide range of lengths and strength, is very tough, will bend with its loads, is easily climbed, easily fabricated, has good insulating qualities, and formerly was available in some suitable species native to every section of the country. It has been employed from the beginning of the industry, and designs embodying its use have kept pace with the development of the art. In designs requiring greater strength in any direction than the pole possesses as a cantilever, such strength can easily be procured by proper guying. The great drawback in the use of wood for very important lines is the relatively short life of timber, but this can be partially, but not entirely, overcome by the use of suitable wood preservatives.

With the rapid increase in transmission line voltages, and the consequent increase in cost of insulation at each structure, it became more and more advantageous to increase the span lengths in order to minimize the number of insulators required. At the same time, load densities were increasing, which justified the use of larger wires, making it mechanically possible to increase the spans. However, each increase in span required a proportionate increase in structural strength, first, because the wind load, with the same area per mile of wire exposed to the wind, must be divided between fewer structures, and second, because the increasing size of wire and length of span made the tension in the wire increase rapidly. At the same time, lengths of line were increasing so that the distance between terminals was often found to be much shorter in a straight line than it was in following the highways. The latter circumstance often made it advantageous to construct the line on a private right of way in order to save length, and at the same time permitted the use of wider bases for the supporting structures.

Steel Adopted for Supports

These circumstances, combined with the greater permanence of steel, probably led to its adoption for supporting structures, as well as the fact that it could be readily designed and its various members proportioned to fit the exact needs by following proven structural theory. The first tower lines, shown in Fig. 1, were designed for about 66,000 volts, using pin type insulators; that is, insulators carrying the conductor in a groove on top to which it was secured by a wire tie. The first steel transmission line in New England was of this type built in 1907–08 from Vernon, Vermont, to Fitchburg, Massachusetts, by C. R. T. Company, and is still in operation. Since that time, however, it has undergone considerable alteration, such as increasing the size of conductor and improving construction at large angles.

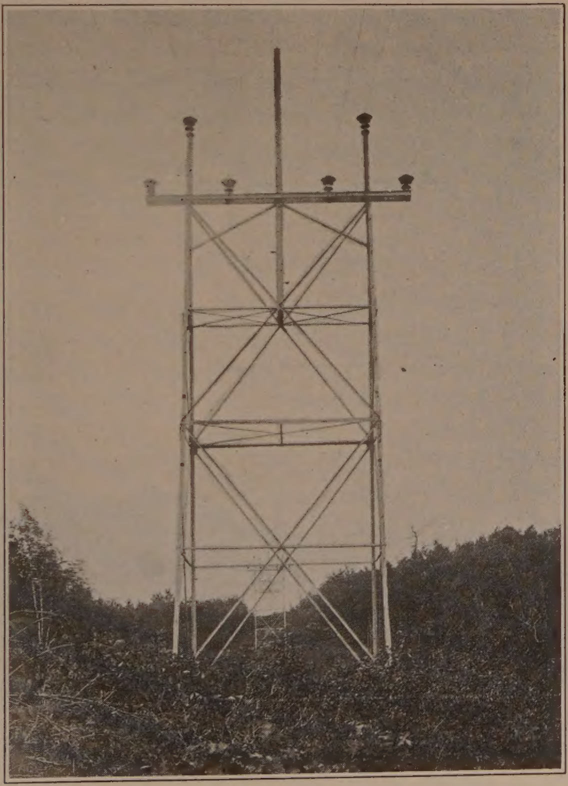

FIG. 1. — EARLY TYPE OF STEEL TOWER USING PIN TYPE INSULATORS

Built about 1908

About 1909 the cap and pin suspension, disc type of insulator was developed, which made it practicable to design for even longer spans and to insulate the conductor with a greater factor of safety, both from an electrical and a mechanical standpoint. In the era just preceding the World War, when the price of structural steel was very low, the conventional type of double circuit tower, in which the three wires of each circuit are placed in a vertical plane on one side of the tower, became very popular, and practically every line then constructed was of that general design.

During the war many lines were constructed for emergency power and for interconnections on wooden structures, because of the increase in the price of steel, the difficulty of getting priority certificates, and the rapidity of delivery and fabrication of pole lines. It was at this time that the advantages of interconnection between central stations first became apparent. Immediately following the war, during the big industrial expansion, the same conditions continued, and inasmuch as it was easy to get native chestnut timber of good quality at that time, all lines of the New England Power Association during and after the war were constructed of wood until the time of the Davis bridge development in 1923.

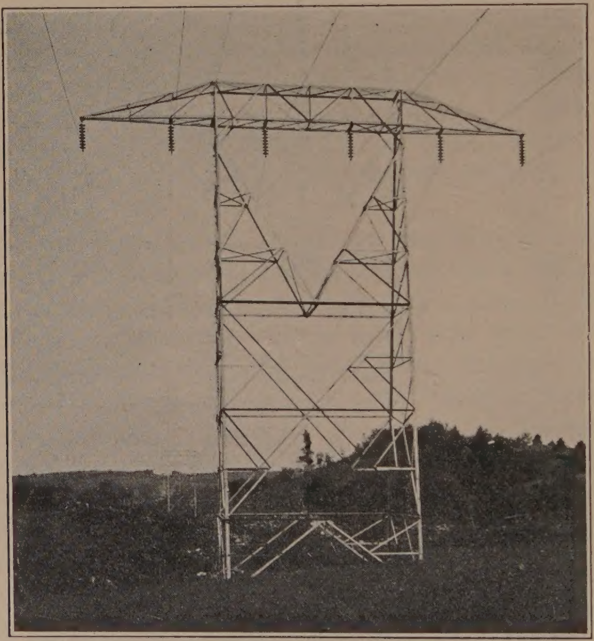

Fig. 2. — Steel Tower for Double Circuits. Horizontal Arrangement of Conductors

Davis Bridge – Millbury Line, 100,000 Volts

In this case the aim was to design a line of the utmost reliability, because the entire block of power, amounting originally to about 60,000 horsepower, but later increased to 80,000 horsepower, was to be transmitted from Harriman Station to Millbury load center, a distance of seventy-five miles. The experience with sleet on the conventional double circuit vertical tower line, culminating in the disastrous storm of November, 1921, induced the company to adopt the policy of constructing all important lines with the conductors arranged horizontally. On that particular line very careful estimates were made comparing the cost of using either two wood pole H-frame lines or one steel tower line with conductors arranged horizontally. When these estimates were studied to cover the cost over a long period of years, including capital cost plus interest, depreciation and maintenance, it was found that there was no advantage of one material over another, except in the matter of permanency, which influenced the ultimate decision. Fig. 2 shows a tower in the line as it was built.

CATENARY CURVE

Except for its own weight and the relatively small wind pressure on the tower, all of the loads supported by the tower must be imposed by the wires supported. This fact makes the determination of the catenary curve one of the most important considerations in arriving at an economical design.

As previously mentioned, the conductivity of the conductors is generally determined by electrical considerations, and is so proportioned that the investment plus the capitalized value of the yearly losses is at a minimum. For a given conductivity, there is a wide range of metals to choose from in specifying the conductor to be used. Almost any mechanical strength within reason may be selected from copper, copper clad, bronze alloys or aluminum cable with a steel reinforcement.

The position assumed by the wire hanging freely between two supports is known as a catenary curve. This curve is very closely approximated by a parabola when the sag does not exceed 10 per cent of the length of the span, which condition prevails in nearly all of the designs. Therefore in computing sag data, engineers use the parabola formulæ in which sag is inversely dependent on the tension, directly dependent on the weight of the wire, and directly dependent on the square of the span. Thus if we have a 1,000 foot span with a conductor weighing 1 pound per foot, the sag would be 125 feet if the horizontal component of the tension is 1,000 pounds. If this tension is increased to 2,000 pounds, the sag would be reduced to 62½ feet; or, if the weight of the wire increases to 2 pounds per foot, the tension would be either 2,000 or 4,000 pounds for the same relative sags; or, if the tension and weight remain constant and the span is decreased to 500 feet, the sag would be one-fourth of that for the 1,000-foot span, and would become 31¼ feet, and 15⅝ feet for the 1,000 and 2,000 pound tensions.

Careful investigation of actual construction data on hundreds of miles of line has indicated that the form of the catenary for the average span will control the normal height of tower. Of course, the same average height of tower can be secured with a longer span by increasing the tension in the conductor. However, all these factors affect the design and weight of structures per mile of line, a typical case being represented by the accompanying curve, Fig. 3, which is taken from our studies of the so-called Davis bridge–Millbury line, and indicates that the bottom of the curve is very nearly horizontal, — a fortunate condition, because the per cent of error is necessarily small if we keep the normal length of span within a reasonable distance of what seems to be the most economical.

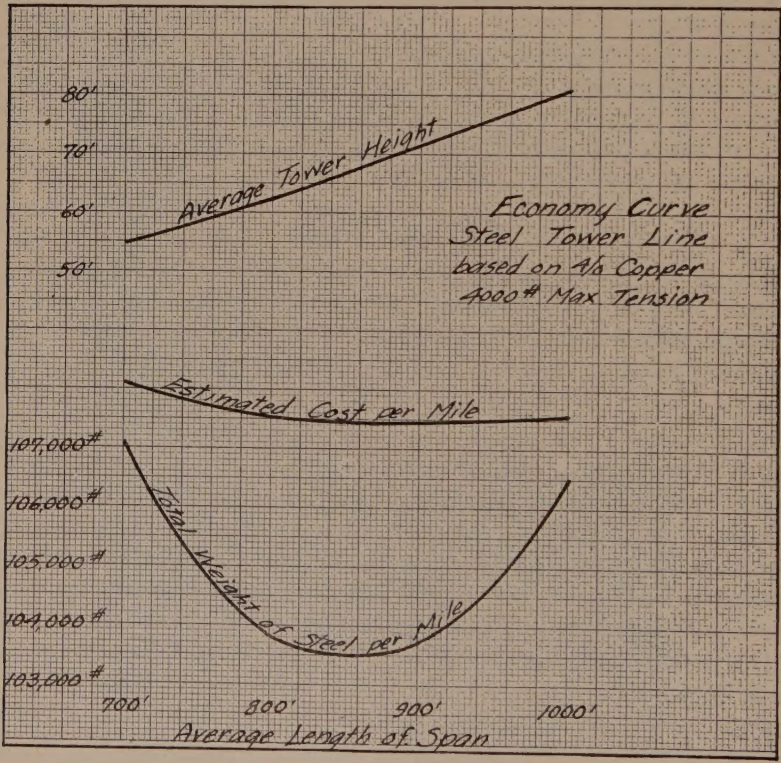

Fig. 3. — Relation of Tower Heights, Weights, Spans and Costs

In designing the catenary the loads imposed on the tower structure must be carefully considered. It is usual to design the structure for a definite proportion of the wires being broken. This proportion is arbitrarily chosen, and is based on experience as well as on the relative importance of the line to be constructed. The greatest amount of uplift on the tower footings generally occurs from the broken wire condition assumed, and must be given very careful consideration in territories similar to New England, where we have a very large amount of expensive excavation. By keeping the length of span at a reasonable figure, with the correspondingly smaller tension in the wire, we are able to save a considerable amount of money which would be spent in excavating very deep foundation holes. In general, the longer the span the higher the tower, the tighter the catenary, and the greater the amount of earth which must be excavated to properly anchor each tower footing.

Single Circuit, Semi-Flexible Type of Tower

A characteristic design of transmission line sponsored by the New England Power Association has come to be known as the New England Power Design, although the towers were actually detailed and fabricated by the American Bridge Company. This line is known to us as the single circuit, semi-flexible type, and has basic design theories somewhat opposed to previous practice.

In this design the line is considered to be divided into a number of structural units, each of which is about three-quarters of a mile in length and consists of one anchor tower at each end, and one or more intermediate flexible towers, all of which structures are securely tied together with two high strength steel ground wires attached to the top of the legs.

Each flexible tower, Fig. 4, is designed to carry all transverse loads from wind forces or otherwise as an independent unit, but to be flexible in the direction of line so that in case of unbalanced longitudinal loads it will deflect away from the break until the longitudinal loads are again balanced by the unbroken wires. This action transfers the longitudinal load to the high strength ground wire, which in turn transmits it back to the nearest anchor tower, at which structure it is carried into the foundations. This type of construction makes it necessary to provide footings for the resistance of longitudinal load only at strain tower locations, which average about three-quarters of a mile apart. The flexible tower as designed with four legs in pairs, each pair being close enough together so that a single footing can be used for both legs. It has been found by actual, full-sized field tests that a large part of the flexibility of such a tower occurs at or below the ground line, for which reason we have always used only earth anchors, preferring to maintain this feature at the expense of many solid rock excavations.

IMPORTANT PRINCIPLES OF DESIGN

In this type of design, four things are of vital importance:

First. — All towers must be designed to withstand any possible transverse load.

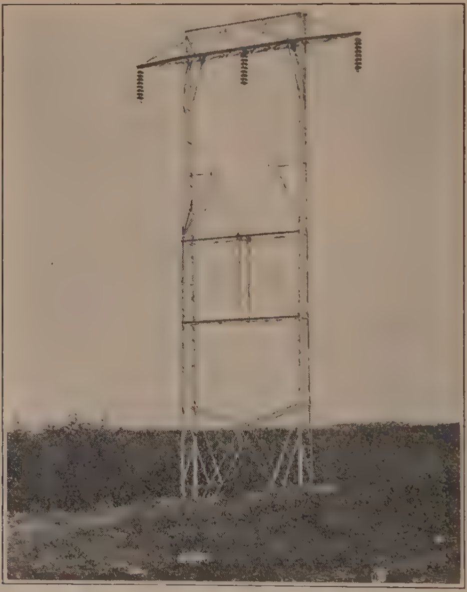

FIG. 4. — SINGLE CIRCUIT, SEMI-FLEXIBLE TYPE OF TOWER

Second. — Flexible towers must be capable of sufficient deflection to allow the loads to balance in the unbroken wires without crippling the tower itself.

Third. — The ground wires must have sufficient cross section and strength to transmit these unbalanced loads to the nearest anchor tower.

Fourth. — The anchor towers must be designed to break all the wires supported in order to prevent any progressive failure of towers in one structural unit from communicating itself to the next.

All these points have been carefully investigated by the company and proven by actual full-sized tests. In New England, which is subject to the occurrence of very heavy sleet storms, the conductor, particularly for this type of line, should be designed and sagged so that the liability of breakage is small.

Advantages of Flexible Type of Tower

The first reaction of many engineers in looking over the flexible type of line is that it is used chiefly on account of cheapness of construction. This is not the case, because the cost of two well constructed single lines of this type is about the same as a rigid double circuit line which has the conductors in a horizontal plane. The flexible type is preferred by this association because it is considered to have the following distinct advantages:

First. — A greater number of structures per mile can be used with a correspondingly greater sag and larger factor of safety in the conductors.

Second. — This makes possible two independent lines at practically the cost of a single double circuit line, which should make the line as a whole more reliable.

Third. — Two ground wires can be provided in the position which has been found to be most effective in protecting the conductors and insulators from lightning discharges.

Fourth. — The average height of the conductor is kept as low as possible by the greater number of low towers. This is very important, when it is considered that the voltage gradient of induced lightning is proportional to the height of conductor above ground, and has a value of about 100,000 volts per foot of height.

Fifth. — The line insulation can be increased at very small structural expense, and in this way make the line more nearly immune from lightning disturbances.

Type used for Fifteen Mile Falls Development

A line of this type is being built for distribution from the Fifteen Mile Falls Development on the Connecticut River, which will transmit the current at a voltage of 220,000. In designing this line there has been adopted the same average span which has proven satisfactory on present construction. The conductor itself is 795,000 c. m., A. C. S. R., having an ultimate strength of 27,000 pounds per square inch, and having a diameter of slightly over one inch. The ground wires are one-half inch plow steel and have strength and other characteristics comparable to the aluminum conductor. These wires will be sagged so that they will support ice deposits having a radial thickness of 2½ inches on the wire without exceeding the elastic limit. It therefore seems impossible for these wires to break under any conceivable load. Strain towers will, however, be inserted in the line at every seventh structure, principally for the purpose of damping out longitudinal oscillations which are sometimes caused by wind blowing directly along the line. Very heavy towers will be used at intervals of about two to three miles to provide absolute insurance against possible progressive failure.

All footings will be of steel, with proper areas to provide a safe bearing on the soil, and with sufficient depth to be safe against uplift. On 220,000-volt lines built previously it has been necessary to use multiple insulator strings because of the heavy conductor tensions. This it is planned to avoid entirely, because actually it is necessary to use only single strings of standard strength insulators at suspension points, and a single string of heavy duty insulators at strain points. Arcing rings of the latest design will be used with all insulator strings to keep lightning discharges from burning the conductor and for insulator protection. A bridle type of insulation, consisting of two strings in the shape of a "V," will be used to support the center conductor in order to prevent all transverse movement, thereby making it possible to use a tower only 19 feet wide, whereas a width of about 30 feet would be necessary if this conductor were supported on the usual type of string, free to swing in any direction. This design also provides flaring legs at the top, because it is desirable to offset the ground wire to a position as near the outside conductors as possible. The models which were made of alternate designs indicate that the flaring legs are more pleasing in appearance than straight legs.

Tower Spacing

In designing a line it should be noted that execution of the work generally requires that the towers be purchased long before the surveys are completed. It is therefore necessary and desirable to use as few types of towers as possible. Most lines are designed to have a suspension tower, — a strain tower capable of taking any angle liable to be encountered. The design of the line is not complete until the towers have actually been located. This is done by plotting the profile of the line and shifting a sag templet, as shown in Fig. 5, over it until the most economical tower spacing is found. Towers must be used at each location selected which will be capable of taking the loads for the particular conditions. In general, the towers will be designed for some maximum length of span which should not be exceeded at any location. One of the things which causes considerable trouble, at least in New England territory, is to prevent uplift or a reversal of stress on the suspension insulators. Unless the engineer is very careful towers may be located in a depression in such a way that there will be no weight on the insulator, and during cold weather the conductor may be pulled up to a point where an arc is formed to the tower steel.

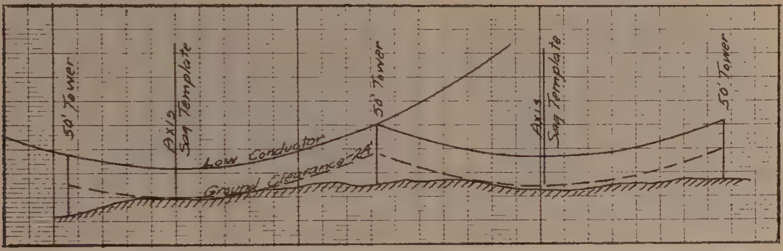

FIG. 5. — METHOD OF DETERMINING TOWER SPACING

Contrary to the practice on most other types of structure, it is permissible in transmission line towers to use single-bolt connections. This is permissible because in a great many instances the stress to be transferred is very small, and long years of experience have indicated that such connections are satisfactory. It is only in very special cases that riveted connections are used.

DESIGN OF TOWERS FOR TRANSMISSION LINES

BY H. O. WEBER *

CONTRARY to an opinion which seems to be more or less prevalent, there is nothing mysterious or very complicated about the design of transmission towers. It is true that they exist in quite a variety of shapes and sizes, but their purpose is the same in all cases, — to support overhead wires carrying electrical energy. Figs. 6, 7, 8 and 9 show, in order, a single circuit tower designed for 220,000-volt service, a double circuit tower designed for 110,000-volt service, another 220,000-volt single circuit tower, but a little different in size and shape from the first, and a comparatively high tower used for a reasonably long span over a navigable stream where considerable clearance was required above the water. The

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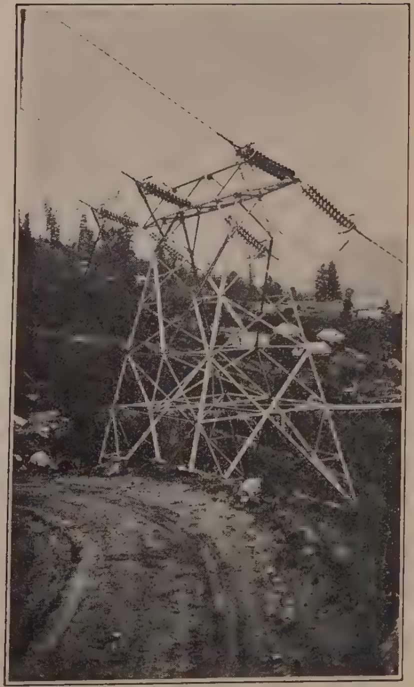

FIG. 6. — SINGLE CIRCUIT TOWER FOR 220,000-VOLT SERVICE

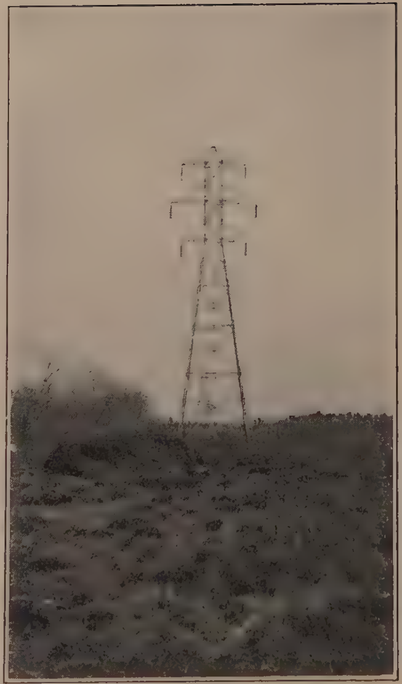

FIG. 7. — DOUBLE CIRCUIT TOWER FOR 110,000-VOLT SERVICE

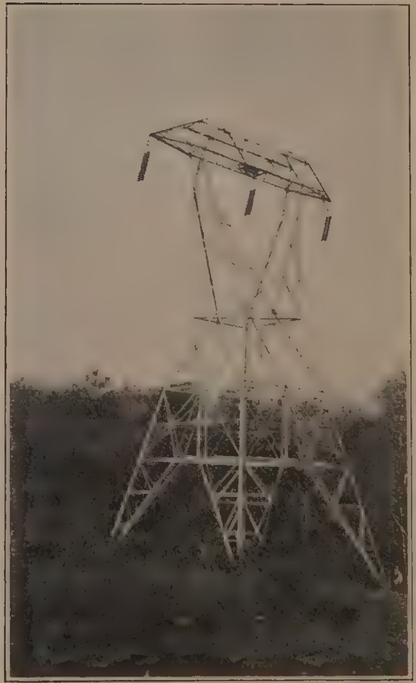

FIG. 8. — SINGLE CIRCUIT TOWER FOR 200,000-VOLT CIRCUIT

last one is an entirely different structure, in appearance, at least, from the others, but its principle is the same.

Towers for transmission lines may be divided into three general classes of structures: Class I would include the self-supporting tower which is designed to resist loads in the direction of the line as well as across the line; Class II, would include the flexible or semi-flexible bent, having rigidity across the line but depending on the wires to resist load in the direction of the line; Class III would include the steel pole type which may be similar to either Class I or Class II structures in principle, but which has a small ratio of base width to height. The use of a tower of this sort can be justified only where right-of-way limitations will not permit the use of a wide-based tower, such as along city streets, or to take advantage of a location where the width must be kept down to or near to the dimensions of a wood pole. The principles of design for Class I structures are very little, if any, different from those required for Class II and Class III, and therefore discussion will be limited to the design of the towers in Class I.

Types of Rigid Towers

This class of structure may be divided into three types. One type is what is called the suspension or standard line tower, which is used on tangents on the line, and is designed to take transverse and vertical loads from the wires and the additional longitudinal load due to one or more broken conductors.

The second type is an angle tower used at angles in the line and designed ordinarily for the same loads used in the design of the suspension tower, but, in addition, takes transverse wire pull due to an angle in the line. These towers are generally located so that the axis of the cross-arms bisects the angle in the line, thus dividing the wire pull load due to the angle equally between the two transverse faces of the tower.

The third type is the strain or anchor tower used wherever it is desirable to dead-end the line, and is designed to take the dead-end pull from all the wires, as well as the vertical and transverse loads.

If there are a large number of angles in the line, and their sizes vary between wide limits, it may be desirable to design two different angle towers, using one for smaller angles and one for the larger, but this is very seldom justified, and it is customary to use the dead-end tower at the heavy angles and thus keep the number of different kinds of towers to a minimum.

After the economic and electrical features have been studied to determine the arrangement, size and spacing of the conductors, and also

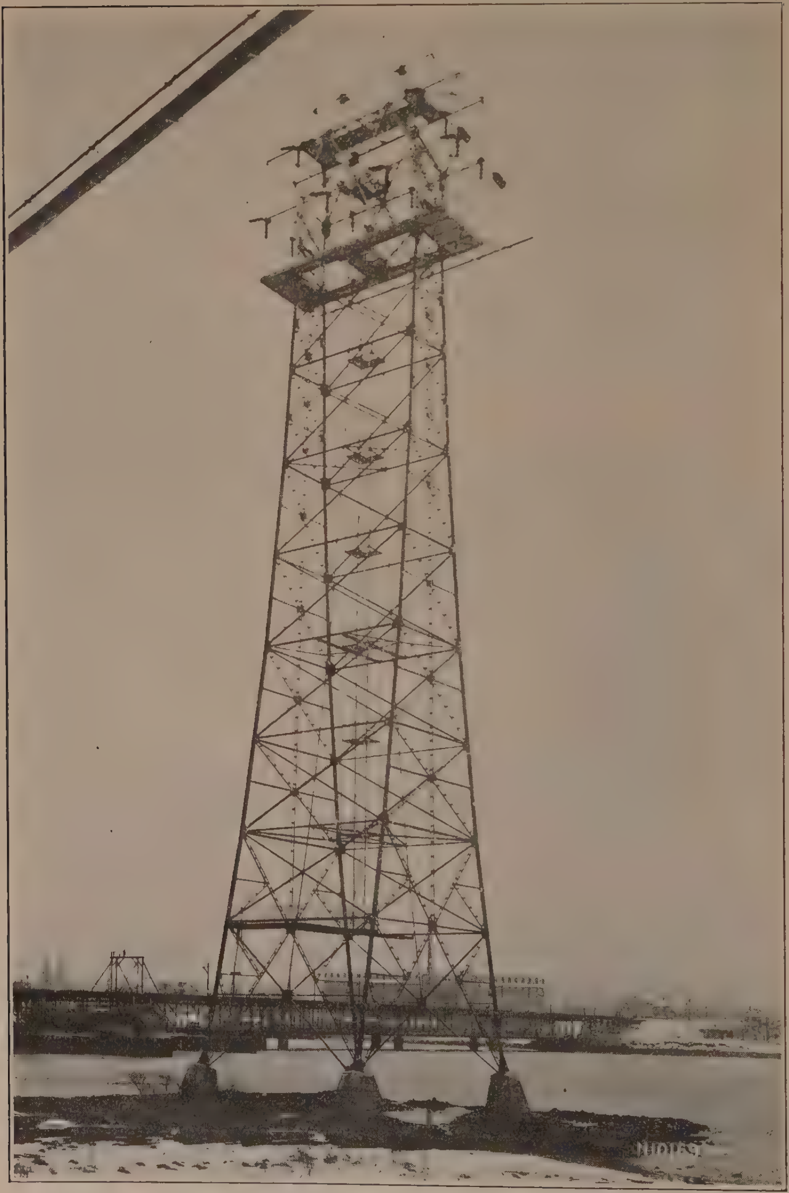

Fig. 9. — High Tower for Long Span over Navigable Water

to determine the sag and span which in turn determine the tower height, computations may then be made of the loads brought to the towers from the wires followed by the actual design of the structure.

Loading Conditions

It is a comparatively simple matter to compute these loads which the wires bring to the tower when the loading assumptions are decided, that is, when the basis of loading has been determined; but to determine the amount of ice and the wind pressure to use as a basis of loading on the wires, and the overload capacity which the towers should have under these assumed loads, requires very careful consideration and the exercise of about all the judgment in our possession. If too light a loading is assumed the line will not come up to expectations, and, on the other hand, if the loading assumed is unreasonably heavy, the cost of the line will be unnecessarily increased.

The territorial United States has been divided into three districts by the National Electrical Safety Code, which recommends certain definite loadings to be used in each of these districts. These districts are designated for loadings, as light, medium and heavy, and New England is in the heavy loading district. In the heavy loading district the resultant loading is specified as the weight of the wire plus the weight of one-half inch of radial ice combined with a horizontal wind pressure of 8 pounds per square foot of surface. The loading in the other two districts, medium and light, are expressed in the same way, the medium loading being the same, except that the ice is one-fourth inch in radial thickness; and in the light loading district no ice is assumed and the wind pressure is 12 instead of 8 pounds.

Factor of Safety

It is quite generally agreed that nothing less than these loads should be used as the basis of tower loading as well as wire loading, but it is well known that occasionally the loading will be much more severe and that broken wires will sometimes occur. There should, therefore, be some reserve strength or overload capacity in the towers to carry the loads which occur at such times. The extent to which provision should be made for these abnormal loads in the towers is an economic question as to the amount which should be spent to insure reliability of service. In other words, it is simply a matter of spending money if the best is wanted.

For a line which is to be built in the heavy loading district, I believe the minimum strength of any tower should be that required to support the wires when none are broken but when they are all loaded to their full capacity, namely, when there is sufficient ice and wind load in combination to strain the wires right up to their breaking point. That should be the minimum, and the additional strength that should be provided in the towers to take the strain due to loads from broken wires should be determined by the performance of existing lines during severe sleet storms.

The chart in Fig. 10, which was prepared during an investigation to determine the factor of safety and tower loading to be recommended for use in the design of an important line, shows the comparative strength of towers on some existing lines in the heavy loading district. On this chart the factor of safety is plotted against thickness of ice coating on the wires, in all cases acted on by a wind pressure of 8 pounds per square foot, and each one of these curves shows the factor of safety that the suspension towers for that particular line would have under these assumed loads if two wires were broken. This is a purely arbitrary set-up, but it shows the comparative strength of the towers on these lines under the same loadings. The curve marked No. 1 is quite widely separated from the other five, showing that the strength of these towers was considerably more than for any in the main group. It shows that the suspension towers on this line had a factor of safety of about 1½, even when the conductors were loaded with 1½ inches of ice and when two wires were broken. This is about three times the strength of line No. 6, and very nearly twice the strength of line No. 4, which is an average for the main group. In that particular case the operating company which

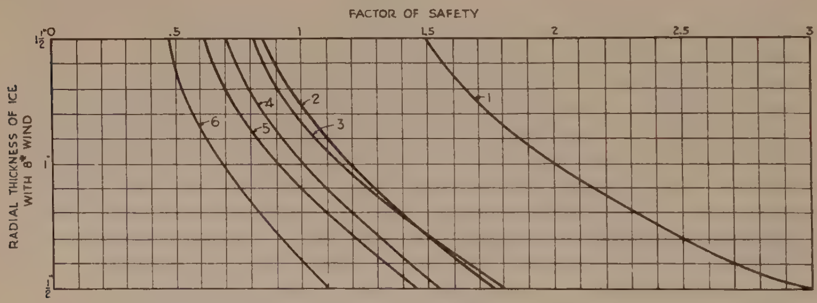

FIG. 10. — COMPARATIVE TOWER FACTOR OF SAFETY

Double circuit towers, with two wires broken built the line felt that they were justified in making the necessary expenditure to provide towers which would be absolutely safe regardless of what might happen in the way of a sleet storm. Curves Nos. 2 and 3 are for towers much less conservative but which have more than average strength. The most interesting part of this analysis was the fact that the three lines represented by curves Nos. 4, 5 and 6 had, a short time previous to the preparation of this chart, been through very severe sleet storms. Line No. 4 came through the storms without any sign of failure, while lines in the same territory, but of lighter construction, were so badly damaged that it was necessary to rebuild them. Tower lines Nos. 5 and 6 were here in New England. They were very close together, — in fact, for a considerable distance, on the same right of way, — and yet a severe sleet storm which wrecked line No. 6 so badly that it was rebuilt, damaged the towers of line No. 5 only to the extent of a few bent cross-arms and other minor injuries. Whatever loading is assumed is more or less arbitrary, since one cannot tell exactly what happens under these severe sleet storm conditions. The wires do break, but it is not known what offsetting factors there are, such as the balancing effect of other wires on the tower at the time of breakage, slippage of the wires in the connections, and all that sort of thing. However, the chart shows conclusively that, regardless of the loading assumptions, about the only way to be reasonably sure that the towers will go through the most severe sleet storms without damage is to provide them with about the strength of those in line No. 4. Of course, it is not necessary to build towers of this strength for every line, but if we desire to have them come through sleet storms without damage, it appears to be the thing to do. This is an economic consideration which must be considered for each particular case.

Perhaps the term "factor of safety" used in the chart should be defined as it applies to transmission towers, for the reason that it does not have the same meaning as when ordinarily used in other lines of structural design. A tower is a frame structure made up of both tension and compression members. Of course, a compression member, if it is not just a short member where bending does not enter into the design, will fail when the elastic limit strength is reached, and when one compression member in the tower fails it probably means failure of the tower as a whole, so that the factor of safety of overload capacity as applied to towers simply means the amount of load in excess of the design load which the tower will stand before the stress in any of its compression members reaches the elastic limit.

UNIT STRESSES

For towers whose members are composed of single angles connected by bolts, the following unit stress will provide a factor of safety of about 1½ if the steel used is Class A basic open hearth steel, as specified by the American Society for Testing Materials for structural steel for buildings.

In practically all towers of ordinary size some of the members are connected by a single bolt, and a great many of them are connected through one leg only; in fact, the largest percentage of those in the web system are so connected. Differentiating between the stress which should be permitted for those connected through both legs and those through only one leg, the following are the allowable unit stresses in pounds per square inch:

For angles connected through both legs:

Tension	24,000
Compression ($\frac{l}{r}$ not over 150)	$27{,}000-115\frac{l}{r}$ (maximum 20,000)
Compression ($\frac{l}{r}$ from 150 to 200)	$21{,}000-75\frac{l}{r}$

When angles are connected through one leg only (about 10 per cent less than the above values are what the writer is using at the present time).

For angles connected through one leg:

Tension	21,000
Compression ($\frac{l}{r}$ not over 150)	$24{,}000-110\frac{l}{r}$ (maximum 18,700)
Compression ($\frac{l}{r}$ from 150 to 200)	$18{,}000-70\frac{l}{r}$

Bolt values:

Shear	20,000
Bearing	40,000

STRESS ANALYSIS

With these assumptions and principles the loads and stresses may be determined in each of the tower members, so as to select a suitable structural section to carry the computed maximum stress with the desired factor of safety. Except for the vertical loads this stress analysis is probably most easily accomplished by the use of stress diagrams. Except for the torsional effect of a longitudinal load due to a broken wire acting at the end of a cross-arm, there is very little difference between the stress analysis for a transmission tower, and, for example, a trestle bent. In making the stress analysis it is advisable to consider each face of the tower and each set of loads separately. There are so many combinations of loads that the only safe thing to do is to avoid confusion and keep them as nearly separate as possible. The first step as indicated in Fig. 11, after having determined the wire spacing, is to make an accurate scale drawing of the tower outline; then compute the various loads, and apply them at the point where they would act. In each face of the tower loads should be kept separate, and those shown represent the loads which would be applied at the panel points of the tower, due to wind on the tower, and at the points of conductor attachment, due to transverse wind on the wires. The pull from an angle in the line should be included if the tower is an angle tower. The loads in the third column, although indicated as acting in the same direction and in the same plane as the others, are the longitudinal loads produced by the broken wires.

The next step is to compute the reactions of the tower on the foundations, and with this data construct the load diagrams and from them the stress diagrams. As previously stated, there should be little difficulty in constructing these stress diagrams, but there is a slight catch in computing the stress by means of a diagram for the torsion condition. I believe the easiest way to handle it is to replace the longitudinal load which acts at the end of an arm by an equal force on the center line of the tower and two couples which would produce the same torsional moment. It will then be a simple matter to draw the diagram for the shear of each face, but it must be remembered that the same torsional shear is acting in each of the four faces, and is equal for each face if the tower is square. The catch is that, due to the fact that this shear is acting in each one of the four faces, the stress produced in the leg by the loading in one face will be balanced by the stress in the face acting at right angles when the tower legs are vertical and the web members are capable of taking either tension or compression.

When all of the stresses in each of the members for each set of loads has been determined, it is advisable to prepare a table giving the designation of the members and the amount and kind of stress in each for each set of loads. It is then a simple matter to find the maximum total stress in tension or compression.

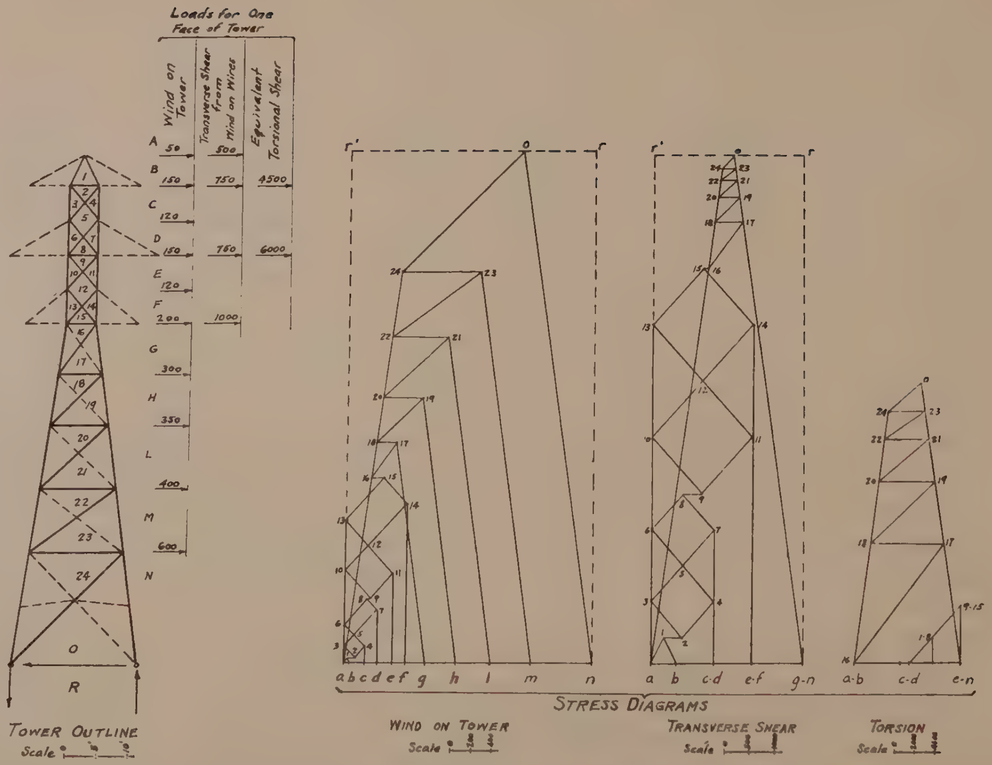

FIG. 11. — TOWER LOADINGS AND STRESS DIAGRAMS

Selection of Member

As for the selection of the structural section for each member, that, of course, is no different in principle from the procedure for any other frame structure, except that as the members in the web system as a rule carry small stresses and are very light, it is well to avoid the use of gusset plates in the connections. As an example of the method of selecting the section to be used in any one member, it may be assumed that for a lower section of the leg member in the tower, Fig. 11, with the particular loading, the maximum stresses are 41,000 pounds in compression or 34,000 pounds in tension. The procedure would be exactly as in the design of any compression member, by trial and substitution of the value of the radius of gyration for whatever member is tried in the compression formula. In this case if a factor of safety of 1½ is used, that is, the compression formula $2{,}700-115\frac{l}{r}$, it will be found that as far as strength is concerned either a 5″ x 5″ x ⅜″ angle or a 4″ x 4″ x ½″ angle will suffice. In this particular case the 5″ x 5″ angle would be selected, assuming that it is just as easy to obtain, because its larger dimensions offer better connection conditions, it is lighter than the 4″ x 4″ angle, and is slightly stronger as a column on an assumed length of 9 feet between supports. The selection of the material to be used in any of the members should be made in the same way, giving attention to the connection details, and making sure that the framing represents the most efficient layout from the standpoint of unsupported length of compression members, and that sort of thing. Unless one is a very experienced designer he probably would find, when he came to design the section for each of these members, that by going back and making some changes in the paneling and dimensions he would be able to make some reductions in size and a consequent saving in weight.

The foundations should be designed to resist the compression or tension in the tower leg and also horizontal shear applied at or near the ground line. Steel anchors are quite commonly used, and are very satisfactory, but considerable care should be exercised to make sure that they offer sufficient resistance against the horizontal shear, as even a slight movement of the tower legs at this point may cause indeterminate stresses of considerable magnitude in the structure.

General Comments

Galvanizing is now used very nearly universally for the protection of steel in transmission towers of ordinary sizes, where bolted connections are satisfactory. Galvanizing is not practicable where riveting must be done, and in such cases it is practically essential that the towers should be painted.

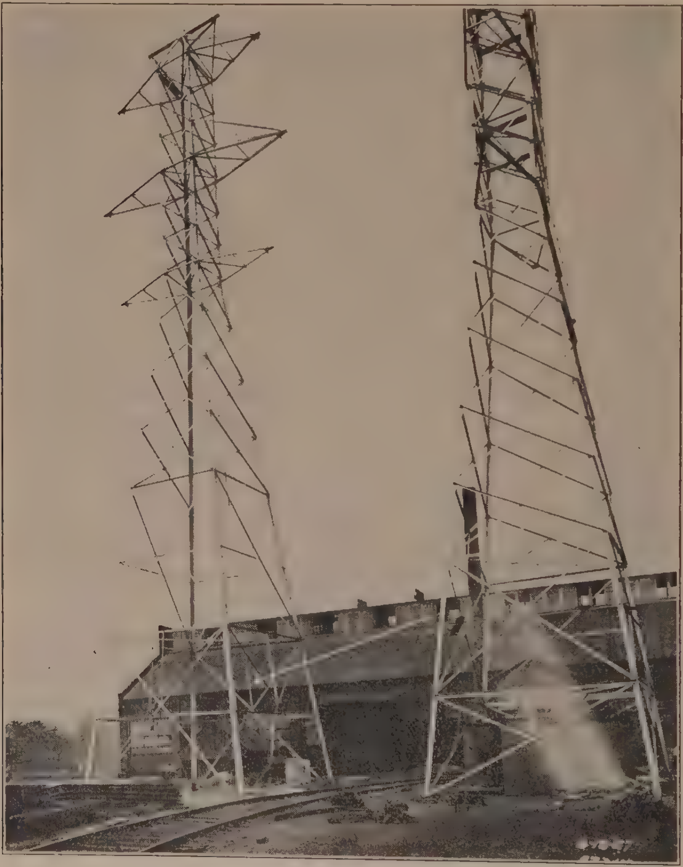

Fig. 12. — Completed Tower tested for Loadings and for Maximum Load, causing Buckling in Corner Post

Quite frequently after a tower is designed, if there are a large number of them to be built of the same kind, one of them is fabricated complete and tested. Fig. 12 shows a case where a tower was tested not only for the loads for which it was designed, but where the loads were gradually increased until tower failure occurred. This was done to determine the weakest point in the tower, and in this case failure occurred by buckling of the corner post.

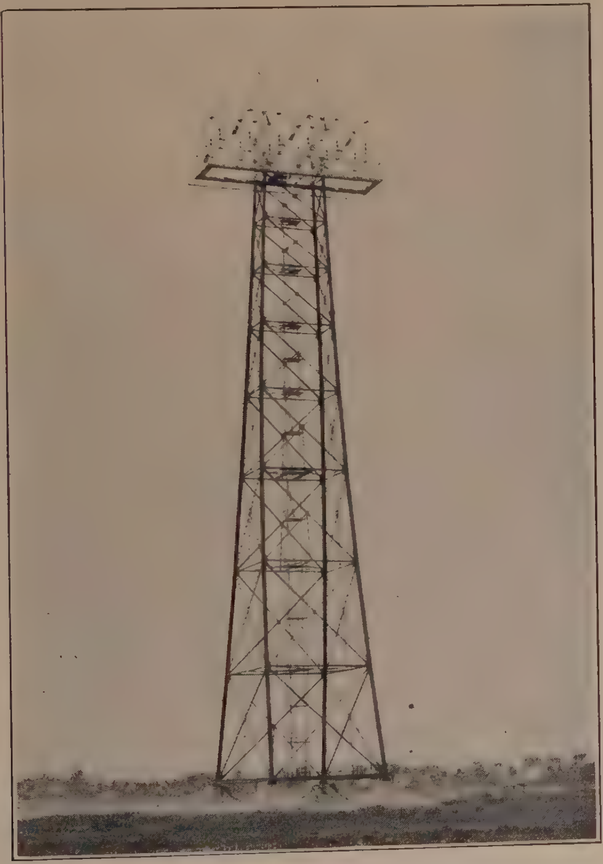

FIG. 13. — STEEL TOWER 277 FEET HIGH ABOVE TOP OF FOUNDATIONS

Span of conductors, 2,000 feet at 150 foot clear height above navigable water

To forestall any idea that all towers are comparatively small and therefore not of much account, perhaps suggesting a tendency to belittle in one's mind the design of structures for this purpose, Fig. 13 shows a tower designed to carry one end of a 2,000-foot span over navigable water where a clearance of 150 feet over the water was required, and where it was decided that the towers should be made strong enough to resist any loads that might be brought to them from the conductors. They are 277 feet high above the top of the foundations. The working unit stresses provided a factor of safety of 2 in this corner post, and the total stress was some 370,000 pounds, approximately; in other words, the ultimate strength that it was assumed could come to that leg was over 700,000 pounds. The make-up of the tower leg was two 15-inch 45-pound channels and an 18″ x ⅜″ plate, making a compression member similar to light bridge chords. The foundations for each of the four legs are of considerable size. At the base the legs are 70 feet apart in the direction of the line and 45 feet across the line, and the amount of concrete in each one of the four footings is over 250 yards, so it seems a transmission tower can be quite a sizable structure.

Discussion

SIDNEY A. MARTIN (by letter):* Good design of transmission towers should recognize the requirements of economy in shop fabrication and field erection. The following points are given as of interest to the tower designer from this point of view.

It is now practically the universal practice to have all transmission tower material furnished completely galvanized, and in erecting it to use galvanized bolts in all connections.

There are several processes of galvanizing. The three most common of these are briefly described as follows: The hot process consists of the dipping of the piece in molten spelter. The electric process consists of the coating of the piece by electric contact. Sherardizing consists in placing the piece in an air-tight tube filled with zinc oxide and then heating it to the required temperature and removing it after cooling.

The hot process is most commonly used for coating structural material. Before the material is galvanized, it must be cleaned of all rust, grease, paint and mill scale. This is done by immersing the piece first in a bath containing a solution of sulphuric acid to remove the objectionable matter, and then in water to remove the acid. The piece is then ready for the galvanizing pot.

Material to be galvanized should come from the mill with all identification marks put on with Taylor's chalk instead of paint, and after it is fabricated the assembling marks should be stenciled (stamped) on each piece so that they will not be obliterated by galvanizing.

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* Engineer with Jackson and Moreland, Park Square Bldg., Boston, Mass.

The galvanized tower can be made of thinner material than if painted, and requires little or no maintenance cost.

There are some points, however, that should be considered in the design to reduce the cost of galvanizing and avoid delays in this shop operation. The lengths of the pickling and galvanizing pots should be known and all material lengths kept a few inches short of these, so that the material can be completely cleaned or galvanized in one operation, and not one end at a time. These limited lengths will practically govern the tower make-up by deciding the points where post angles will splice, thus governing panel points for web members, and by limiting the length of web members also.

Bent pieces take up room in the pots, and if very long have to be dipped one end at a time, hence should be avoided if possible; also avoid a design that requires several members to be riveted together before galvanizing.

Using galvanized bolts at all connections also has an effect on the design. These bolts usually cost the fabricator more per pound than he sells the tower material for (including bolts). Hence the percentage of bolt weight to other material weight should not be too high. Wherever possible, one member is connected directly to the other without the use of connection plates, making each bolt count and reducing the number of pieces in the tower. This is a saving in weight as well as in erection cost and in handling of material along the line. Very often the number of bolts required to connect one member to another decides the size of the members rather than the stress to be developed.

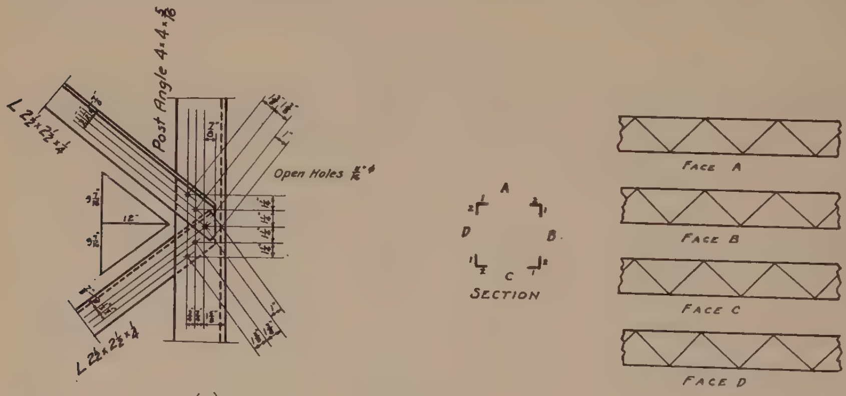
This occurs usually in members of short length with high stress, where there will be less weight added by increasing the width of the member to permit the use of the required number of bolts than to introduce an extra member, such as a connection plate. This often determines the size of a leg angle as well as a web member. Fig. 14 shows a typical connection for diagonal members to a post angle. It will be seen from this sketch that it would be impossible to get the three holes necessary in diagonal angles less than 2½ inches in width, or to get the holes in a post angle less than 4 inches in width.

In outdoor substations the design often consists of several towers with box girders placed between them to support the various switches, etc. The box girders usually are composed of chord angles at the four corners of the square cross section connected together with single lacing of angles in the four faces.

These girders can be made very simple for shop fabrication if the following points are taken care of:

1. Keep the switch bases or other equipment that connects to them spaced symmetrically with respect to the center of the girder.
2. Arrange the single lacing angles as indicated in Fig. 14.

Note that this procedure gives an arrangement of diagonals which is the same on all four faces; also note that where two diagonals come together on one leg of a chord angle there are no connections at this point on the other leg. This method eliminates interference when the diagonals are turned in, as in the usual practice, and there will be no holes that may be covered up in the other leg of the chord angle. This arrangement permits all four chord angles to be made to the same detail, thus requiring only one shop templet and reducing detail drawing costs. It also increases duplication, which in turn reduces shop cost and simplifies the assembling of the girder in the field.



(a) (b)

FIG. 14

(a) Typical connections of diagonal members to post angle
(b) Box girder for out-door substation supports

The amount of duplication in shop details is a big factor in reducing fabrication costs. For this reason the design of as many towers as possible is kept the same. Towers of various heights are designed alike for the height of the shortest tower, and the variations in height taken care of by the addition of extensions to the bottom of the short tower.

The basket of the tower is that portion having vertical posts and to which the cross-arms are attached. Sometimes it is necessary to vary the height of the basket, but in such cases the lower portion of the tower (*i.e.*, the section with sloping sides) is made to the same detail as other towers in the line unless stress requirements demand otherwise.

Often a special condition in the line can be taken care of by the use of special cross-arms, keeping the balance of the tower like others in the line.

QUESTION: I would like to ask Mr. Weber if the wind loading of 8 pounds mentioned is per linear or square foot.

MR. WEBER: It is 8 pounds per square foot on the projection of the ice-coated wire, which is considered as one inch more than the diameter of the wire. Of course, 8 pounds is a low figure for two reasons. It is assumed to be acting in combination with a heavy sleet load, and the surface is assumed to be cylindrical and smooth. The Weather Bureau records indicate that the combination does not occur very frequently, although in some cases there is a high wind after the sleet forms. An 8-pound wind pressure is equivalent to a true velocity of about fifty-six miles per hour, which is not a mild wind.

QUESTION: How are the torsional strains proportioned when the plan section is not a square?

MR. WEBER: That is a rather difficult thing to explain without the use of diagrams of some sort, and furthermore, this is an indeterminate problem, and probably for that reason it is not accomplished in the same way by all designers. My method is to consider the area of the tower in plan and construct the diagonals at the cross-arm level. With the lengths of the diagonals as arms, find the forces which, acting as two couples, would produce an equivalent torsion moment. These forces applied normally at the ends of the diagonals and resolved will give the shear to be taken in each face of the tower. This gives equal distribution for a square tower, and forces inversely proportionally to the widths of the faces when the plan section is rectangular.

QUESTION: When there are two diagonals in the panels designed to take compression, what is considered the unsupported length of the member?

MR. WEBER: Assuming that you refer to a case in which the two diagonals are connected at their intersection, I would consider half their length for bending about the axis normal to the plane in which the members lie, and three-quarters of their length of the axis in that plane.

QUESTION: Have you a method by which you can figure the forces required to support the mid-point of a compression member, say a column 20 feet high?

MR. WEBER: In the leg members of the transmission tower there are certain members which are not taking any computed stress but whose purpose is to keep the leg members from buckling. These redundant members must be good for compression as well as tension, and their limit of $\frac{l}{r}$ is from 250 to 300.

QUESTION: Do insulators swing, or are there strain insulators between the conductors and the tower faces?

MR. WEBER: On high voltage lines the insulator is free to swing in either direction.

QUESTION: If a wire breaks does the string of insulators swing?

MR. WEBER: Yes, and that condition reduces the tension, but in general, on anchor towers, the strain insulators make a fast job of it. It becomes part of the wire.

QUESTION: In figuring compression, if it is over a good many panels, do you consider continuity?

MR. WEBER: Not unless at the panel points it is more than just supported; for example, consider the failure that I showed on the test tower. It failed very close to a point where it was supported, and the leg angle bent into the shape of a letter "S." It buckled above and below a panel point.

QUESTION: I understand it is customary to design the foundations of steel alone, without the use of concrete.

MR. WEBER: Our practice is to use steel alone or in combination with concrete. There are various patented details of this. For protection they are galvanized. The footings are a grillage of I-beams or any shapes that will transfer the load to the earth and will develop an earth cone (30° to the vertical) against uplift.

QUESTION: Is the burial of the lowest diagonals a patented feature?

MR. WEBER: It is a patented feature and used by the American Bridge Company to take care of ground line shear. Other methods use bearing plates just under the ground. We use a framed structure which resists the shear through its resistance to overturning on its base.

QUESTION: Is galvanizing damaged in erection?

MR. WEBER: I presume it is. We inspect the lines weekly and very often get reports of very bad rust, in which case an investigation of conditions is made. The galvanizing on the bolt appears to be much poorer than on the steel itself, consequently the rust from the bolts discolors the steel. We have towers that have been up since 1907, and there is no sign of deterioration on most of them, but we have had a lot of rusted bolts. Bolts have been, in general, sherardized. They are galvanizing them now, and the threads are cleaned by a centrifugal process.

QUESTION: I would like to ask how galvanizing compares with painting in cost.

MR. WEBER: It is generally cheaper to galvanize. It costs about 1 cent a pound, which is cheaper than painting, when you consider the life of the galvanized structure.

QUESTION: What is the unit tensile stress allowed in the ground lines for the latest type of towers of the New England Power System described by Mr. Booker?

MR. BOOKER: The ground wire has an ultimate strength of 27,000 pounds, roughly, and the tension at the heaviest loading will be about 5,000 pounds, or about one-fifth of its ultimate, which is very low. We generally pull it up to about one-half, but in this case we are figuring on one-fifth.

OF GENERAL INTEREST

VITRUVIUS

By Edward Grossman

It is rather difficult to write a biography of a man who did not leave any biographical material, except stray remarks in his own writings. Nor is the task lightened by access to contemporary records, for these are exceedingly scanty. Apparently Vitruvius, whose "De Architectura" taught innumerable architects, engineers and builders for fifteen hundred years, was a retiring man who did not figure in the headlines of the day. Yet he did a great amount of engineering work and filled several important positions. His *magnum opus* is evidence enough.

Marcus Vitruvius Pollio was born probably in the first quarter of the first century B. C. (that is, sometime in the period 100–75 B. C.), and died during the later part of the reign of the Emperor Augustus (30–14 B. C.). He apparently not only designed buildings, such as the basilica and Aedes Augusti at Fano, but must have designed and built water-supply systems, bored tunnels, and have done some research in materials of construction; for not only does his work treat of architecture but of all the other things also. Although he very likely compiled much of his book from ancient sources, yet his comments thereon show a sagacity and discrimination that come only after a great deal of experience.

It is known that during the reign of Augustus he was appointed superintendent of ballistæ and other military engines. For his public services he was pensioned for life by Julius Cæsar.

Because Vitruvius is not mentioned in contemporary records to any great extent, and because in his writings, done during the last years of his life, he complains about being alone and broken in health, it is quite evident that his personality was not a pleasing one. His ethics are high indeed, and quite in contrast with those of his time. Since he was not with the crowd, it was, in consequence, against him. Another probability is that he was not sufficiently servile, and therefore did not partake of honors to the extent that a less capable but more supple man would have done.

Speaking of the general qualifications of an architect he states: "An architect should be ingenious, and apt in the acquisition of knowledge; he should be a good writer, a skillful draftsman; versed in geometry and optics, expert at figures, acquainted with history, informed on the principles of natural and moral philosophy, somewhat of a musician, not ignorant of the sciences both of law and physics, nor of the motions, laws, and relations to each other of the heavenly bodies. . . . Moral philosophy will teach the architect to be above meanness in his dealings, and to avoid arrogance; it will make him just, compliant, and faithful to his employer; and what is of highest importance, it will prevent avarice gaining an ascendancy over him; for he should not be occupied with the thoughts of filling his coffers, nor with the desire of grasping everything in the shape of gain, but by the gravity of his manners and a good character should be careful to preserve his dignity."

Another evidence of the single-mindedness of Vitruvius is his method of discovering subterranean springs to be used as sources of water supply. Sources of water, he states, may be easily found "if the springs are open and flowing above ground." If, however, the sources are not so evident, he recommends that "before sunrise one must lie down prostrate in the spot where he seeks to find it, and with his chin placed on the ground and fixed, look around the place; for the chin being fixed, the eye cannot range upward farther than it ought, and is confined to the level of the place. Then where the vapors are seen curling together and rising into the air, there dig, because those appearances are not discovered in dry places." Only a man with an actual love for his profession, and without regard for those social dignities which are to some the alpha and the omega of existence, can bring himself to the undignified position of lying on the ground at dawn to watch for vapors curling out of the ground to indicate the presence of water.

Under the conditions obtaining in Rome during his lifetime, the ways of the professional man were not such as to be conducive to Vitruvius's peace of mind. He utters bitter complaints, which show that, to his mind, purely professional knowledge and service were not adequately recognized or appreciated by his countrymen. In the city of Ephesus an ancient law provided that if the cost of a given work completed under the plans and specifications of an architect did not exceed the estimate, he was commended "with decrees and honors," but if the cost exceeded the estimate by more than twenty-five per cent, he "was required to pay that excess out of his own pocket." Vitruvius wishes that "such a law existed among the Roman people, not only in respect to their public but also to their private buildings, for then the unskillful could not commit their depredations with impunity, and those who were the most skillful in the intricacies of their art would follow the profession."

Vitruvius mentions three instruments used in surveying at the time: the dioptra (possibly the forerunner of the telescope), the level (spirit level, most likely), and the chorobates, a rod about twenty feet in length, having at its ends two legs of equal length and at right angles to the rod. Braces, with vertical lines accurately marked on them, were fastened between the rod and the legs. The chorobates was apparently used as a batter-board, for the instrument was leveled up by plumbing the vertical lines with plumblines. When the vertical lines were truly vertical, the horizontal rod served as a datum for determining levels on the building under construction.

With regard to clay pipe as used for drains and other purposes, Vitruvius speaks of earthen pipe which should be not less than two inches thick, and "tongued at one end, so they may fit into one another." The joints were coated with quicklime and oil.

On the subject of healthful locations for cities as well as dwellings Vitruvius had well-defined ideas, especially in regard to drainage and other sanitary considerations. Marshy, foggy and odorous locations were to be avoided.

Foundations were extremely important in his mind. He says that they "should be carried down to solid bottom, if such can be found, and that they should be built thereon of such thickness as may be necessary for the proper support of that part of the wall standing above the natural level of the ground. They should be of soundest workmanship and materials, and of greater thickness than the walls above." He also mentions the use of piles driven by machines.

In harbor design he lays down certain principles, such as the need of a protection to the harbor, either from a natural promontory, if that is available, or by means of a breakwater or sea-wall. He explains what mixture of lime and pozzuolana will set under water, and the construction of a cofferdam.

It is truly regrettable that we do not know more of this great engineer. Libraries are filled with the common events in the lives of lesser men, but the joys, sorrows, victories and defeats of Vitruvius are a sealed book to us forever.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Boston Society of Civil Engineers

January 22, 1930. — A regular meeting of the Boston Society of Civil Engineers was held today in Chipman Hall, Tremont Temple, Boston, Mass., and was called to order by the President, Frank E. Winsor, at 7.15 P.M.

There were 120 members and guests present. The President appointed as secretary, *pro tem*, Mr. J. B. Babcock, who announced that the following had been elected by the Board of Government on January 22, 1930, to membership in the Society:

Grade of Member: Carle Whittier Greene, Arthur J. Giuranovich, Frank Louis Lincoln, Mary Olga Soroka.

Grade of Junior: Paul R. Chandler, Roland R. Chaput, Raymond E. Edson, George L. Gorbell, Arnold L. Guild, Alfred A. Lockerbie, Theodore R. Love, Philip D. White.

The President announced that the minutes of the previous meeting (December 18, 1929) would appear in the January Journal.

Attention was called to the fact that Miss Soroka is the first woman to be elected to membership in the Society.

The President then introduced Mr. Kenneth F. Akers, Fire Protection Engineer, with Fay, Spofford & Thorndike, Consulting Engineers, Boston, who gave an illustrated talk on "Fire Protection Engineering as applied to Municipalities." This paper included the principal features of the recent survey conducted in Boston by the Albert Russel Erskine Bureau, Harvard University, in co-operation with the National Fire Protection Association.

After Mr. Akers' talk the following members and guests discussed the subject: Dr. Miller McClintock, Director, Albert Russel Erskine Bureau, Harvard University; Eugene C. Hultman, former Fire Commissioner, city of Boston; Percy Bugbee, Assistant Managing Director, National Fire Protection Association; I. Osgood, Engineer, Boston Board of Fire Underwriters; Henry A. Fiske of the Grinnell Company, Providence, R. I.; Frank Bradford, Director of Safety and Fire Protection, Boston & Maine Railroad; H. O. Lacount, Consulting Engineer, Associated Factory Mutual Fire Insurance

Company; Frederic H. Fay, Consulting Engineer, Fay, Spofford & Thorndike; William A. Bryant, Consulting Engineer; John F. Pierce, former City Manager, Springdale, Pa.; and Mr. Akers.

The Society expressed its appreciation of the discussion by members, and gave a vote of thanks to the guests who had taken part in this meeting.

Meeting adjourned at 9.30 P.M.

J. B. BABCOCK, *Secretary pro tem.*

Designers Section

FEBRUARY 5, 1930. — Chairman Sutherland and Vice Chairman Harsch being absent, the Clerk of the Section called the meeting to order in Myers Hall at 6.15 P.M. The Clerk announced that the next meeting, in March, would be the annual meeting of the Section. A motion was made and passed for the appointment of a nominating committee to present nominees for officers and to report at the annual meeting. Following the usual custom the three most recent past chairmen of the Section were appointed, namely, Waldo F. Pike, Scott Keith and William D. Henderson.

"Ready Mixed Concrete" was the subject of the paper presented by Miles N. Clair, Vice President of the Thompson & Lichtner Company. Following his paper several members asked questions or related their experiences with the product. One of the proprietors of a local mixing plant spoke briefly. Mr. E. W. Roemer of the Boston Building Department made remarks.

Twenty-nine members and guests were present. The meeting adjourned at 7.30 P.M.

NORMAN P. RANDLETT, *Clerk.*

Sanitary Section

FEBRUARY 5, 1930. — Preceding the meeting, fifteen members attended dinner at Patten's restaurant.

The meeting was called to order at 7.15 P.M. by the Chairman. Thirty-two members and guests were present.

The appointment of a nominating committee was announced, comprising E. Sherman Chase, Chairman, Edward Wright and John L. Howard.

Prof. Gordon M. Fair of the Harvard Engineering School was then introduced. The subject of his talk was "Italian Marshes, Bavarian Fish Ponds, Rhenish Rivers, and Dutch Canals — Impressions of an Itinerant Sanitary Engineer," and was illustrated with lantern slides.

The speaker gave an interesting account of his observations on a trip through Italy, Germany and Holland. He described the malaria-elimination work being done in Italy, the use of diluted sewage in Bavarian ponds in which fish culture is carried out on a commercial scale, recent sanitary projects in the Ruhr and adjacent districts, and Dutch sanitary problems.

Following Professor Fair, Mr. H. P. Eddy, Jr., was introduced, and he talked of his observations on a recent European trip, dealing chiefly with refuse disposal in England and Scotland. His talk was illustrated, but owing to failure of the lighting facilities at the start of his talk he was obliged to speak "in the dark," the illustrations being shown following the discussion.

The subjects of these talks were discussed by Messrs. Wright, Kingsbury, Gage and Eddy, Jr.

The meeting adjourned at 9.45 P.M.

GEORGE G. BOGREN, *Clerk.*

APPLICATIONS FOR MEMBERSHIP

[February 15, 1930]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

Brady, James Henry, Dorchester, Mass. (Age 45, b. Boston, Mass.) Spent three years at Franklin Union, course of surveying, and two years at Pratt Institute, Brooklyn, N. Y. Experience: 1915–17, rodman and transitman, Metropolitan Park Commissioner; 1917–19, draftsman, Fore River Shipbuilding Corporation; 1919–21, New York Navy Yard, as draftsman; 1921–23, draftsman, New York Edison Company; 1923 to date, civil engineer, Metropolitan District Commission. Refers to *W. H. Cronin, Ernest Mathers, E. P. McSweeney, E. H. Rogers.*

Markham, Martin James, Stoneham, Mass. (Age 22, b. Ware, Mass.) Graduate of the Stoneham High School and entered Northeastern University in 1927. During co-operative periods has worked for Morton C. Tuttle Company, Whitman & Howard as rodman, and for John F. Rand, of Melrose, as instrumentman. Refers to *H. B. Alvord, C. O. Baird, G. B. Gee, J. W. Ingalls, W. E. Nightingale.*

NEW MEMBERS

Members

Bolde, Alexander C., 117 Stratton Street, Dorchester, Mass.
Greene, Carl W., 457 Franklin Street, Melrose, Mass.
Soroka, Mary O., 35 Lee Street, Cambridge, Mass.
West, William B., 18 Ashburton Place, Boston, Mass.

Juniors

Leahy, James J., 12 Granite Street, Somerville, Mass.
Love, Theodore R., 30 Summer Street, Natick, Mass.
Smith, Joseph A., 151 Central Avenue, Everett, Mass.

DEATHS

Guy H. Chase . . Jan. 26, 1930

Vol. XVII FEBRUARY, 1930 No. 2

BOSTON SOCIETY OF CIVIL ENGINEERS

FOUNDED 1848

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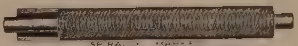

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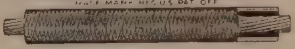

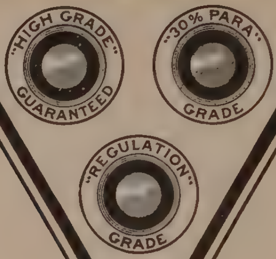

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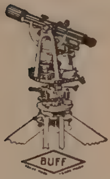

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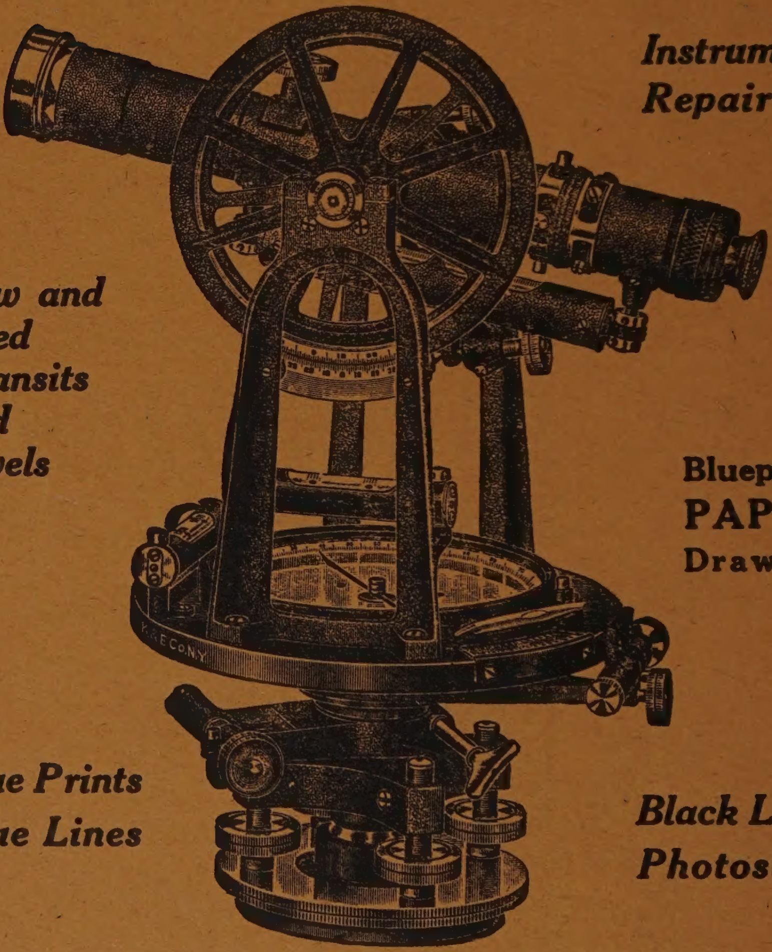

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